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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01J 17/20, 61/12, 61/52

A1

(11) International Publication Number: WO 00/16365

(43) International Publication Date: 23 March 2000 (23.03.00)

(21) International Application Number: PCT/US99/20865

(22) International Filing Date: 16 September 1999 (16.09.99)

(30) Priority Data:
60/100,869 17 September 1998 (17.09.98) US

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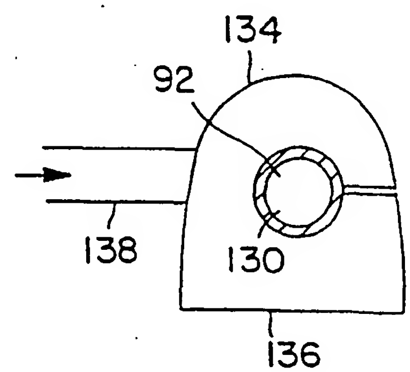
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: LAMP WITH IMPROVED DICHROIC REFLECTOR

(57) Abstract

A discharge lamp includes a light transmissive envelope (92), a discharge forming fill disposed in the envelope which emits light when excited, and a coating (130) disposed on the envelope, wherein the coating is configured to selectively transmit light emitted by the fill in accordance with wavelength and to provide a first gradual transition from a first wavelength region, e.g. the blue region, of high transmittance to a second wavelength region, e.g. the green region, of reduced transmittance. The coating may be further configured to provide a second gradual transition from the second wavelength region of reduced transmittance to a third wavelength region, e.g. the red region, of high transmittance. Preferably, the transitions occur over a broad wavelength range, e.g. 10–75 nanometers. The fill comprises sulfur, selenium, tellurium, indium halide, or other metal halide fills which produce a continuous spectrum by molecular radiation. The coating comprises a multi-layer dichroic coating having relatively few layers, e.g. ten or less.



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LAMP WITH IMPROVED DICHROIC REFLECTOR

This invention was made with Government support under Contract No. DE-FC01-97EE23776 awarded by the Department of Energy. The Government has certain rights in this invention.

BACKGROUND

1. Field of the Invention

The present invention pertains to discharge lamps. More particularly, the invention relates to electroded or electrodeless lamps including a bulb bearing a coating or a covering for improving the color of the lamp.

2. Related Art

An example of such a lamp is disclosed in U.S. Patent No. 5,773,918 (hereinafter referred to as the '918 patent), entitled LAMP WITH LIGHT REFLECTION BACK INTO BULB, which is herein incorporated by reference in its entirety.

As is well known in the art, bulbs may be utilized in combination with dichroic reflectors to alter the output spectrum of the lamp. Such reflectors may be disposed directly on the bulb or may be discrete reflectors spaced from the bulb. Fig. 1 corresponds to Fig. 18 of the '918 patent and illustrates a dichroic reflector 130 disposed on a spherical bulb 92 which is located in a microwave cavity 134 closed by a mesh 136. For many applications the use of a dichroic reflector in combination with certain bulb fills (e.g., sulfur, selenium, metal halides, etc.) results in the recapture of non-useful components of light, some of which is re-absorbed and re-emitted as useful light.

However, conventional coating techniques for the lamp arrangement shown in Fig. 1 are relatively expensive and the resulting coatings have limited lifetimes at the high (e.g. about 1000°C) surface temperature of the quartz bulb during lamp operation.

SUMMARY

It is an object of the present invention to provide an improved color spectrum from a discharge lamp while maintaining a suitable lamp system efficiency and life time.

According to one aspect of the invention, a discharge lamp includes a light transmissive envelope, a discharge forming fill disposed in the envelope which emits light when excited, and a coating disposed on the envelope, wherein the coating is configured to selectively transmit light emitted by the fill in accordance with wavelength and to provide a gradual transition from a first wavelength region of high transmittance to a second wavelength region of reduced transmittance. Preferably, the transition occurs from about 90% of full transmittance in the first wavelength region to within 10% of a level of reduced transmittance in the second wavelength region over a range of at least 10 nanometers. More preferably, the transition occurs over a range of between 20 and 40 nanometers. The coating may comprise a multi-layer dichroic coating having ten or fewer layers. Preferably, the coating comprises a multi-layer dichroic coating having seven or fewer layers. The fill may comprise, for example, sulfur, selenium, tellurium, or a metal halide fill producing a continuous spectrum by molecular radiation. Preferably, the coating is further configured to provide a second gradual transition from the second wavelength region of reduced transmittance to a third wavelength region of high transmittance. In the preferred embodiment, the first wavelength region corresponds to the blue wavelength region, the second wavelength region corresponds to the green wavelength region , and the third wavelength region corresponds to the red wavelength region. Preferably, the second transition occurs from within 10% of a level of reduced transmittance in the second wavelength region to about 90% of full transmittance in the third wavelength region over a range of at least 10 nanometers. More preferably, the second transition occurs over a range of between 30 and 60 nanometers.

According to another aspect of the invention, a discharge lamp includes a light transmissive envelope, a discharge forming fill disposed in the envelope which emits light when excited, the fill producing a continuous spectrum by molecular radiation, and a coating disposed on the envelope, wherein the coating is configured to selectively transmit light emitted by the fill in accordance with wavelength and to provide a gradual transition from a first wavelength region of high transmittance to a second wavelength region of reduced transmittance, wherein the first and second wavelength regions are selected in accordance with the spectrum characteristics of the fill to provide modified color characteristics. In the preferred embodiments, the

fill comprises sulfur and the first wavelength region corresponds to the blue wavelength region and the second wavelength region correspond to the green wavelength region. Preferably, the coating is further configured to provide a second gradual transition from the second wavelength region of reduced transmittance to the red wavelength region with high transmittance.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood with reference to the drawings, wherein:

Fig.1 is a schematic diagram of a bulb bearing a dichroic coating.

Fig. 2 is a graph of transmittance versus wavelength for several preferred embodiments of a dichroic reflector according to the invention.

Fig. 3A is a graph of output spectrum for an uncoated sulfur bulb.

Fig. 3B is a graph of output spectrum for a first embodiment of a coated sulfur bulb according to the invention.

Fig. 3C is a graph of output spectrum for a second embodiment of a coated sulfur bulb according to the invention.

Fig. 3D is a graph of output spectrum for a third embodiment of a coated sulfur bulb according to the invention.

Fig. 4 is a graph of output spectrum for a bulb coated in accordance with the second embodiment operated at full power for 1750 hours.

Fig. 5 is a graph of output spectrum for a bulb coated in accordance with the second embodiment operated at reduced power for 1750 hours.

DESCRIPTION

Conventional dichroic reflectors utilize many layers to provide relatively sharp cutoffs at the selected wavelengths. For example, the steepest slope of such sharp cutoff reflectors may be on the order of ten or several tens of percent transmittance / nanometer (nm). The transition for such sharp cutoff reflectors from 90% of full transmittance to within 10% of the desired reduced transmittance may occur over a range of only a few nanometers. In order to achieve such sharp cutoffs, 20 or more layers are generally required. The multi-layer sharp cutoff coatings are subject to significant thermal stresses under lamp operating conditions. Also, the sharp cutoffs

are not well suited to the broad, continuous spectrum of molecular radiation producing fills such as, for example, the sulfur lamp.

According to the invention, a bulb for a discharge lamp includes a thin dichroic coating disposed on the bulb, wherein the coating is configured to provide a gradual transition from a region of high transmittance to a region of reduced transmittance. The transition preferably occurs from about 90% of full transmittance to within 10% of a desired transmittance over at least 10 nm and preferably between about 20 and 40 nm. Preferably the coating is a multi-layer dichroic coating having relatively few layers as compared to a the number of layers for a comparable coating which provides sharp cutoff. Preferably, 10 or fewer layers are utilized and more preferably 7 or fewer layers are utilized. Advantageously, the gradual transition is well matched to the broad and smoothly changing sulfur spectra.

According to the invention, the coating is further configured to provide a second gradual transition from the region of reduced transmittance to a second region of high transmittance. The second transition preferably occurs from within 10% of the desired transmittance to about 90% of full transmittance over at least 10 nm and preferably between about 30 and 60 nm.

A further advantage of the relatively fewer layer coating of the invention is that a thinner coating is more thermo-mechanically robust as compared to a thicker coating.

Fig. 2 is a graph of transmittance vs. wavelength for three preferred embodiments of an optical interference film according to the present invention. As is apparent from the graph, wavelengths in the green region are preferentially reflected back into the bulb. A first embodiment (Coating #1) provides a transmittance of about 50% in this region (corresponding to a reflectance of about 50%). A second embodiment (Coating #2) provides a transmittance of about 40% in this region (corresponding to a reflectance of about 60%). A third embodiment (Coating #3) provides a transmittance of about 30% (corresponding to a reflectance of about 70%).

As shown in Fig. 2, the transmittance of the dichroic reflector transitions gradually from near 100% transmittance in the blue wavelength region to the respective transmittances of 50%, 40%, and 30% in the green wavelength region and then transitions gradually back to near 100% transmittance in the red

wavelength region. The steepest slope of these preferred embodiments is approximately 3.33 % transmittance / nm from blue to green and approximately 1.24 % transmittance / nm from green to red. The transition for each embodiment occurs over a broad range of wavelengths as noted in Table 1 below:

Coating #1: from 90% to 50% over about 50 nm (to 55% over 22 nm); and from 50% to 90% over about 75 nm (from 55% over 35 nm).

Coating #2: from 90% to 40% over about 30 nm (to 44% over 25 nm); and from 40% to 90% over about 50 nm (from 44% over 45 nm).

Coating #3: from 90% to 30% over about 40 nm (to 33% over 36 nm); and from 30% to 90 % over about 60 nm (from 33% over 50 nm).

Table 1

According to the invention, in the examples presented herein the reflectance is configured to account for the spectral variation of the optical depth of the sulfur plasma as a function of wavelength. For example, to provide a relatively flat output spectral distribution for a sulfur lamp the reflectivity of the dichroic coating is preferably increasing from the blue to the green wavelength regions of the spectrum and decreasing from the green to the red region wavelengths of the spectrum. For other fill materials, different reflectivity / wavelength relationships would be required in accordance with the spectrum and re-absorption / re-emission characteristics of the fill. Also, a spectral shift of the reflectance of the dichroic coating may occur during the initial hours of lamp operation due to the high temperature and high electric field stresses on the coating. This spectral shift may be measured and characterized. After the initial shift, the reflectance of the coating stabilizes. According to the invention, the dichroic coating is preferably configured to compensate for the anticipated spectral shift to provide a desired spectrum after the coating stabilizes.

According to one aspect of the invention, a thin and highly uniform dichroic coating is disposed on the outer bulb surface. Such a coating may be provided, for example, through the MicroDyn® sputtering process available from Deposition Sciences Incorporated of Santa Rosa, CA. This process is described in U.S. Patent No. 5,616,224, which is herein incorporated by reference in its entirety. The process

results in a high temperature HeatBuster® type color correcting optical interference film disposed on the outside envelope of the bulb. MicroDyn® and HeatBuster® are registered trademarks of Deposition Sciences Inc.

In the preferred embodiments, the coating is applied to a 35 mm outer diameter spherical bulb using the MicroDyn® sputtering process to provide a high temperature HeatBuster® type color correcting interference film. The bulb has a fill density of about 26 mg sulfur (about 1.4 mg/cc) and 50 Torr Argon. Preferably, the outer bulb is entirely coated and the coating is uniform within about 5% over greater than or equal to about 3π steradians, and most preferably over greater than or equal to about 4π steradians. The coating is designed to withstand continuous operation at about 1000°C without degradation to the film.

Figs. 3A-D are graphs of output spectrum of uncoated and coated sulfur bulbs, respectively, excited by a standard Light Drive™ 1000 microwave discharge lamp from Fusion Lighting, Inc. of Rockville, MD USA.

Fig. 3A is a graph of output spectrum for an uncoated sulfur bulb. The lamp has a correlated color temperature (CCT) of about 5879 and a color rendering index (CRI) of about 79. The chromaticity coordinates are x = .3208 and y = .4028.

Fig. 3B is a graph of output spectrum for the first embodiment (reflectance of about 50%). The lamp has a correlated color temperature (CCT) of about 5181 and a color rendering index (CRI) of about 87. The chromaticity coordinates are x = .3421 and y = .3814.

Fig. 3C is a graph of output spectrum for the second embodiment (reflectance of about 60%). The lamp has a correlated color temperature (CCT) of about 5168 and a color rendering index (CRI) of about 90. The chromaticity coordinates are x = .3417 and y = .3684.

Fig. 3D is a graph of output spectrum for the third embodiment (reflectance of about 70%). The lamp has a correlated color temperature (CCT) of about 4579 and a color rendering index (CRI) of about 88. The chromaticity coordinates are x = .3592 and y = .3692.

In general, coatings having a higher reflectance provide a higher CRI, but a lower efficiency. Conversely, coatings providing a lower reflectance provide a lower CRI, but a higher efficiency. For example, a bulb coated to provide a CRI of about 85 was about 10% less efficient than an uncoated sulfur bulb. A bulb coated to

provide a CRI of about 92 was about 15-20% less efficient than an uncoated sulfur bulb. However, in comparison with other high intensity discharge (HID) lamps which provide a high CRI (e.g. about 90 or more), the coated sulfur bulb according to the invention is highly efficient. Moreover, most high CRI HID lamps use metal halides or other fill additives to achieve better color rendering and these lamps lose their good color characteristics over a relatively short time. Advantageously, the coated sulfur bulb according to the present invention maintains a high CRI over several thousand hours.

Fig. 4 is a graph of output spectrum for a bulb built according to the second embodiment (reflectance of about 60%) comparing an initial spectrum with the spectrum after about 1750 hours of operation at full power. As noted above, the spectrum shifts from its initial value due to the high temperature and high electric field stresses on the coating. The initial spectrum corresponds to a correlated color temperature (CCT) of about 5452 and a color rendering index (CRI) of about 92. The initial chromaticity coordinates were x = .334 and y = .363. After stabilizing, the spectrum corresponds to a correlated color temperature (CCT) of about 5212 and a color rendering index (CRI) of about 83. The chromaticity coordinates are x = .342 and y = .399.

Fig. 5 is a graph of output spectrum for a bulb built according to the second embodiment (reflectance of about 60%) comparing an initial spectrum with the spectrum after about 1750 hours of operation at reduced power (e.g. about 80%). As noted above, the spectrum shifts from its initial value due to the high temperature and high electric field stresses on the coating. The initial spectrum corresponds to a correlated color temperature (CCT) of about 5413 and a color rendering index (CRI) of about 91. The initial chromaticity coordinates were x = .335 and y = .361. After stabilizing, the spectrum corresponds to a correlated color temperature (CCT) of about 4864 and a color rendering index (CRI) of about 88. The chromaticity coordinates are x = .352 and y = .380.

As is apparent from Figs. 4 and 5, it may be desirable to run a lamp utilizing the bulb coating of the present invention at a reduced power level to avoid overstressing the coating and to maintain a high CRI. Another example a bulb built according to the second embodiment (reflectance of about 60%) has operated

substantially continuously at about 80% power for over 8000 hours while maintaining a CRI of about 86.

While the invention has been described with respect to specific embodiments, variations will occur to those skilled in the art. For example, other molecular radiating fills which re-absorb and re-emit light would be suitable. Such fills include, without limitation, selenium, tellurium, indium halides, and various other metal halides. The invention is not limited to the disclosed examples, but on the contrary is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

CLAIMS

What is claimed is:

1. A discharge lamp, comprising:

a light transmissive envelope;

a discharge forming fill disposed in the envelope which emits light when excited; and

a coating disposed on the envelope, wherein the coating is configured to selectively transmit light emitted by the fill in accordance with wavelength and to provide a gradual transition from a first wavelength region of high transmittance to a second wavelength region of reduced transmittance.

2. The discharge lamp as recited in claim 1, wherein the transition occurs from about 90% of full transmittance in the first wavelength region to within 10% of a level of reduced transmittance in the second wavelength region over a range of at least 10 nanometers.

3. The discharge lamp as recited in claim 2, wherein the transition occurs over a range of between 20 and 40 nanometers.

4. The discharge lamp as recited in claim 1, wherein the coating comprises a multi-layer dichroic coating having ten or fewer layers.

5. The discharge lamp as recited in claim 1, wherein the coating comprises a multi-layer dichroic coating having seven or fewer layers.

6 The discharge lamp as recited in claim 1. wherein the fill comprises one of sulfur, selenium, tellurium, and a metal halide fill producing a continuous spectrum by molecular radiation.

7. The discharge lamp as recited in claim 1, wherein the coating is further configured to provide a second gradual transition from the second wavelength region of reduced transmittance to a third wavelength region of high transmittance.

8. The discharge lamp as recited in claim 7, wherein the first wavelength region corresponds to the blue wavelength region, the second wavelength region corresponds to the green wavelength region , and the third wavelength region corresponds to the red wavelength region.

9. The discharge lamp as recited in claim 7, wherein the second transition occurs from within 10% of a level of reduced transmittance in the second wavelength region to about 90% of full transmittance in the third wavelength region over a range of at least 10 nanometers.

10. The discharge lamp as recited in claim 9, wherein the second transition occurs over a range of between 30 and 60 nanometers.

11. A discharge lamp, comprising:

a light transmissive envelope;

a discharge forming fill disposed in the envelope which emits light when excited; and

a coating disposed on the envelope, wherein the coating is configured to selectively transmit light emitted by the fill in accordance with wavelength and to provide a first gradual transition from a first wavelength region of high transmittance to a second wavelength region of reduced transmittance and a second gradual transition from the second wavelength region of reduced transmittance to a third wavelength region of high transmittance, wherein the first transition occurs from about 90% of full transmittance in the first wavelength region to within 10% of a level of reduced transmittance in the second wavelength region over a range of at least 10 nanometers, and the second transition occurs from within 10% of the level of reduced transmittance in the second wavelength region to about 90% of full transmittance in the third wavelength region over a range of at least 10 nanometers.

12. The discharge lamp as recited in claim 11, wherein the first transition occurs over a range of between 20 and 40 nanometers, and the second transition occurs over a range of between 30 and 60 nanometers.

13. The discharge lamp as recited in claim 11, wherein the first wavelength region corresponds to the blue wavelength region, the second wavelength region corresponds to the green wavelength region , and the third wavelength region corresponds to the red wavelength region.

14 The discharge lamp as recited in claim 11. wherein the fill comprises one of sulfur, selenium, tellurium, and a metal halide fill producing a continuous spectrum by molecular radiation.

15. A discharge lamp, comprising:

a light transmissive envelope;

a discharge forming fill disposed in the envelope which emits light when excited, the fill producing a continuous spectrum by molecular radiation; and

a coating disposed on the envelope, wherein the coating is configured to selectively transmit light emitted by the fill in accordance with wavelength and to provide a gradual transition from a first wavelength region of high transmittance to a second wavelength region of reduced transmittance, wherein the first and second wavelength regions are selected in accordance with the spectrum characteristics of the fill to provide modified color characteristics.

16. The discharge lamp as recited in claim 15, wherein the fill comprises sulfur and the first wavelength region corresponds to the blue wavelength region and the second wavelength region correspond to the green wavelength region.

17. The discharge lamp as recited in claim 16, wherein the coating is further configured to provide a second gradual transition from the second wavelength region of reduced transmittance to the red wavelength region with high transmittance.

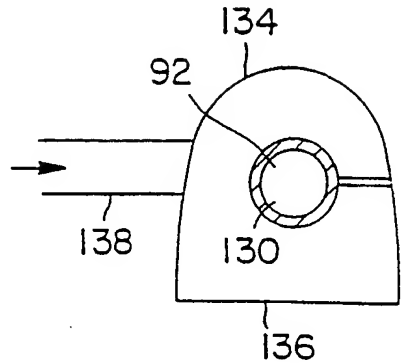
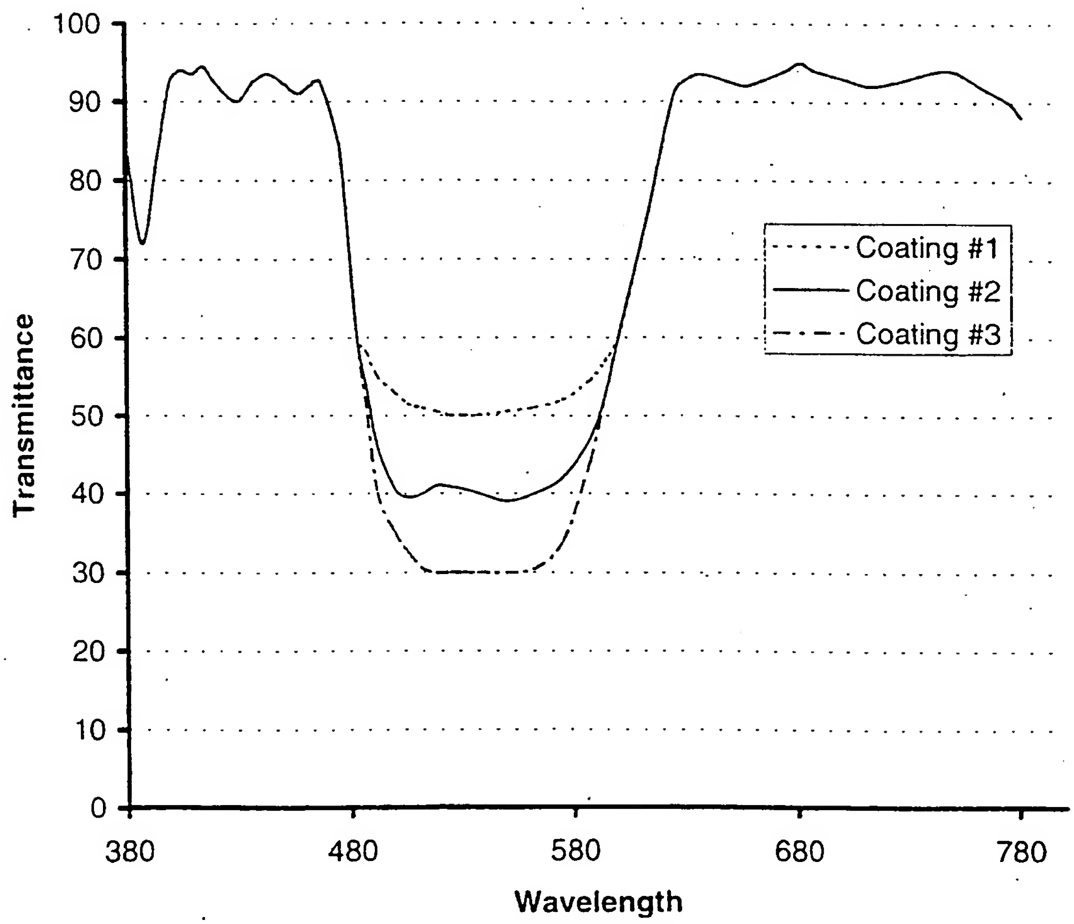

134
92
138
130
136

FIG. 1


100
90
80
70
60
50
40
30
20
10
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Transmittance
380
480
580
680
780
Wavelength
Coating #1
Coating #2
Coating #3

FIG. 2

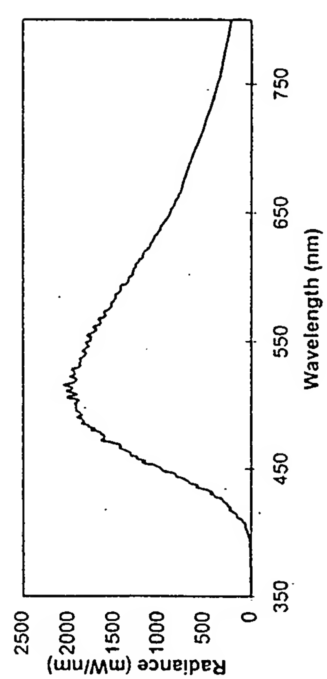


FIG. 3A

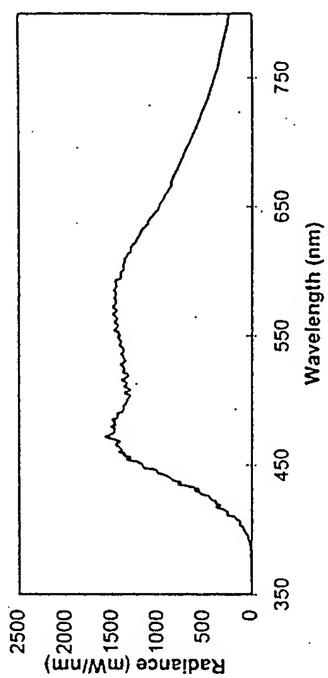


FIG. 3B

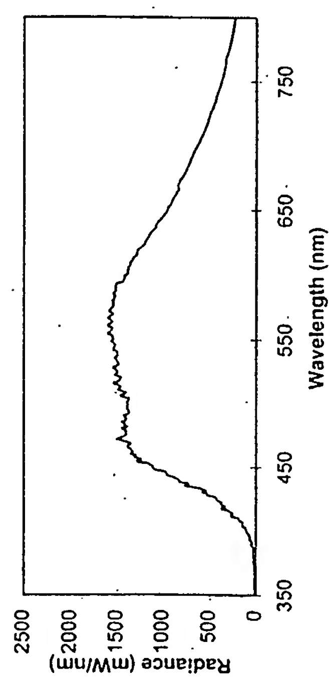


FIG. 3C

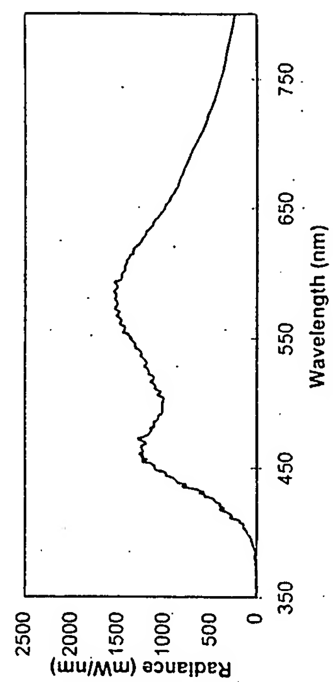
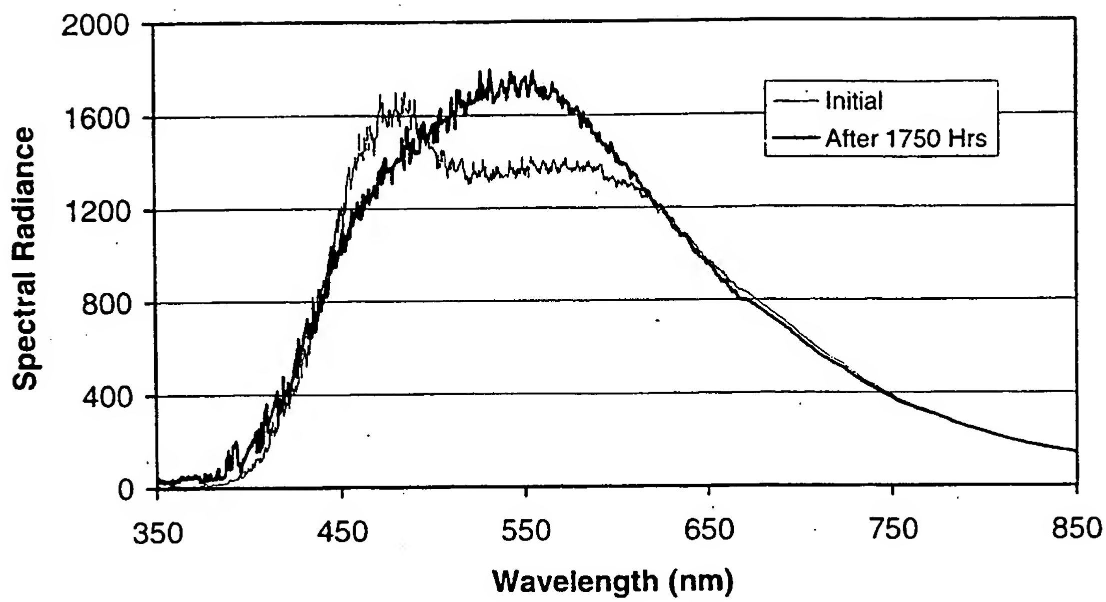


FIG. 3D


2000
1600
1200
800
400
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Spectral Radiance
350
450
550
650
750
850
Wavelength (nm)
Initial
After 1750 Hrs

FIG. 4

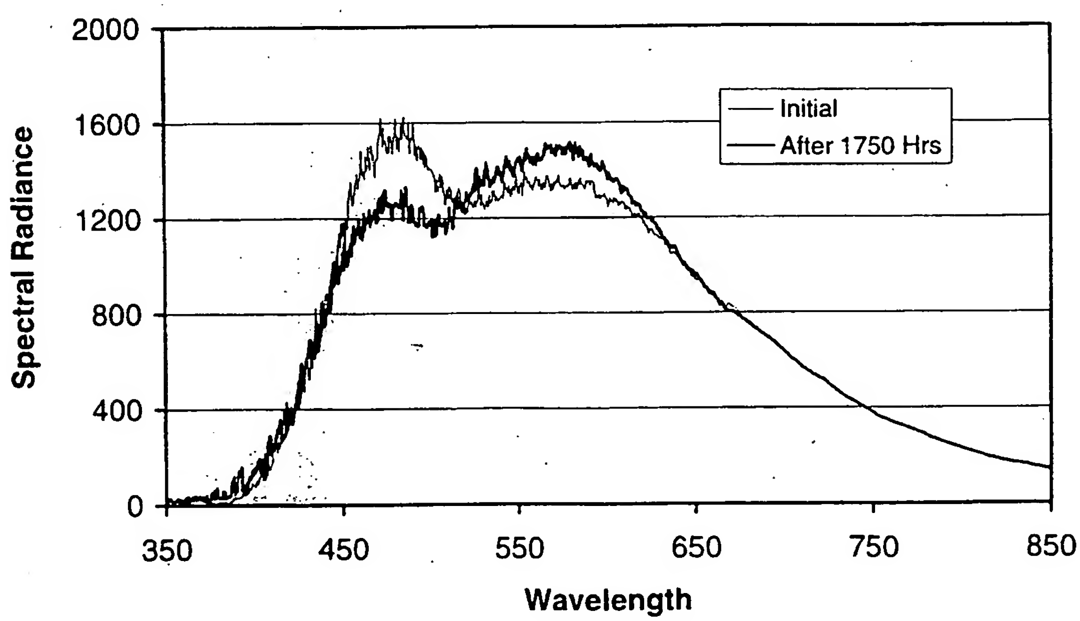
2000
1600
1200
800
400
0
Spectral Radiance
350
450
550
650
750
850
Wavelength
Initial
After 1750 Hrs

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/20865

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01J 17/20, 61/12, 61/52
US CL :313/39, 113
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 313/113, 572, 637, 638, 643; 315/248, 267, 268

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 5,825,132 A (GABOR et al.) 20 October 1998 (20-10-1998), col. 12, lines 43-63.	1-17
X	US 5,804,922 A (DOLAN et al.) 08 September 1998 (08-09-1998), col. 4, line 46-col. 8 line 35.	1-17
Y	US 5,773,918 A (DOLAN et al.) 30 June 1998 (30-06-1998), abstract.	1-17
X, P	US 5,866,980 A (DOLAN et al) 02 February 1999 (02-02-1999), col. 9, line 25-col. 10, line 46.	1-17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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